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Symmetry in Nature

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Explorations in Symmetry

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Contents

Introduction

Symmetry is widely found in nature. Symmetry can be found in snowflakes. Snowflakes are tiny ice crystals, formed within the earth's atmosphere. The research on snowflakes began thousands of years ago, and is still being done today. Since each snowflake is different, they are extremely fascinating to scientists and ordinary people alike. Symmetry can be found in leaves. The research on leaves began thousands of years ago and like snowflakes, is still being done today. Leaves show symmetry in many ways, and their arrangement proves to be remarkable as well. Flowers also show symmetry. Symmetry can be found either radially or bilaterally, depending on the type of flower. Symmetry is correlated to the amount of pollen found in each flower. Nature displays traits of innate symmetry that can be found in snowflakes, leaves and flowers.

Snowflakes

History and discovery

Snowflakes have been falling from the sky since the beginning of time. The earliest documented account of snow crystals and their symmetry was by a Chinese scholar named Han Yin, in 135 B.C. He wrote, "Flowers of plants are generally five-pointed, but those of snow, which are called ying, are always 6 pointed" (Snow Crystals). In Europe, authors began formally documenting snowflakes many centuries later. In 1555, Olaus Magnus, a clergyman, described snowflakes as being many different shapes, however did not seem to make note of their symmetries. In 1591, however, Thomas Harriot correctly identified the now known, six-fold symmetry of snowflakes. Harriot was the first scientist to bring attention to the natural symmetry found in snowflakes.

German scientist Johannes Kepler was famous for his comparison of snowflakes to flowers. Kepler wrote, “Specks of snow fell here and there on my coat, all with six corners and feathered radii. ‘Pon my word, here was something smaller than any drop, yet with a pattern” (Kemp). Since Kepler knew that snowflakes were simply made of ice crystals, he found it fascinating that they could have similar symmetry to flowers. He created an interest in the crystal structure, inspiring scientists for centuries. In 1637, the first detailed record of snowflakes came from René Descartes. The mathematician and French philosopher described the structure of snowflakes as seen with the naked eye, in an extremely thorough manner (Snow Crystals). In 1665, Robert Hooke published a large document detailing everything he knew about snowflakes. He was very interested in looking at them under a microscope. He included many sketches of the snowflakes he had seen. These drawings could show the complexity of snowflakes, something that had not been done before. This document is still available today, and was a major part of the research of snowflakes. The crystal structure of snowflakes was widely a mystery for decades.

Until the 1880’s, the snow crystals were only able to be observed in real time. Wilson Bentley of Jericho, Vermont was extremely interested in the microscopic structure of snow crystals. He began taking photos of the crystals by attaching a camera to his microscope. In 1885, Bentley successfully photographed his first snowflake at age 19. Over the course of 46 years, Bentley had photographed over 5,000 snowflakes at his farmhouse in Vermont. The phrase “no two snowflakes are exactly alike” came from Bentley. In 1920, Bentley started a team with W. J. Humphreys, the chief physicist for the United States Weather Bureau to write the book *Snow Crystals.* Unfortunately, Bentley died just a few weeks after the book was published (Snow Crystals). Bentley paved the way for more scientific research on these ice crystals.

The next researcher was Ukichiro Nakaya, a Japanese physicist. In the 1930’s Nakaya’s lab began the first snowflake research to begin in a laboratory. Nakaya focused on how snowflakes were created in the clouds, rather than their appearance. Nakaya became an expert on winter precipitation, and received funding required to build a walk in freezer. He tried to create his own snowflakes in the freezer, however, natural snowflakes develop during their long journey from the clouds to the ground. In an effort to create his own snowflakes, Nakaya tried to create a snowflake suspended on a fine string. By using a rabbit hair, Nakaya was able to grow isolated snow crystals which closely resembled that of natural snowflakes (Snow Crystals). Ukichiro Nakaya is well known for developing the world’s first synthetic snowflakes in a laboratory.

Size variation

The size of snow crystals changes based on the temperature of the air. The smallest crystals are called “Diamond Dust”. They are no larger than the diameter of a human hair and extremely lightweight. Since they are so lightweight and small, they stay in the air for much longer and look like sparkling dust. Diamond dust is seen when air temperature drops below 0 degrees Fahrenheit. A snow crystals’ size depends on the cloud temperature and the humidity at the time the crystal passes through. As temperatures drop, snowflakes become increasingly more intricate. Snow crystals also become more intricate as the humidity level increases (Means). Snowflake size varies based on the conditions in the atmosphere, so each snowflake size varies.

A common misconception is that snowflakes are what appears as large, fluffy balls. A snow crystal is the single crystal of ice, where the water molecules are lined up in a hexagon shape. Snow crystals are what images show as intricate flakes. A snowflake is a more general term. It can be used to describe anything that falls form the winter clouds. The term snowflake can mean a single ice crystal or could be describing a large group of crystals. Often times, thousands of ice crystals collide, and form what people generally call a snowflake. It is very rare that ice crystals fall without become clumped together as a snowflake. It is ok to call a snow crystal a snowflake; however, it is incorrect to call a snowflake a snow crystal (Kemp). Snowflakes can range from diamond dust, to large clumps of snow crystals depending on the environmental conditions.

Natural Formation of snowflakes

Snowflakes are formed in the earths' atmosphere and then grow as they fall to the earth's surface. Snowflakes begin forming when a particle of dust or pollen particle meets water vapor. When they meet, the water vapor forms an ice crystal on the tiny particle, creating the beginning crystal structure. These crystals are the base for snowflakes. As the ice crystal gets heavier, it begins to weigh more than the surrounding air, then falls. As it falls, more water vapor begins to freeze onto the crystal. Water molecules arrange themselves so that the 6 sided, hexagon shape is repeated. As this process repeats, the snowflake grows larger and larger. A snowflakes' development in the atmosphere doesn't mean that they will fall to the earth. The snowflakes only appear on earth if temperatures are freezing all the way to the ground (King). This is why snow can be found high on mountains even when the temperature is warm on the surface.

Contrary to popular belief, snowflakes are not just frozen raindrops. This is a common misconception, and is widely misunderstood. Frozen rain drops are likely more symmetric to each other than snowflakes are. Frozen raindrops are simply formed when it is raining, but the temperature drops as it falls to earth. Frozen raindrops are called sleet. Snowflakes are formed from water vapor attaching to a dust or pollen particle. Once this small crystal is formed, it begins to further develop. There is no code that determines the structure because it is determined by different growth behaviors.

There are three main behaviors to describe the growth of snowflakes. The first behavior is called faceting. Crystals often contain flat, or faceted, surfaces like those in a gemstone. The word facet comes from the word "face". The first step in growth is always faceting. Each face provides a starting point for growth. Whenever snow appears to be shining, the human eye is just seeing the faces of each snow crystal. Upon closer observation of an individual crystal, a mirror like finish can be seen (Snow Crystals). Faceting is what gives snowflakes their signature shine.

The next growth behavior of snowflakes is called branching. Each of the six corners of the crystal begin to grow faster than rest because they extend further into the air. As the snow crystal grows, the side branches begin to form from the faceted corners of each branch. Branching is an example of growth instability. As the branches get longer, they continue to grow faster because they extend farther into the air. When the crystal forms too quickly, the branches can appear unequally spaced, with little symmetry. The longer a snowflake has to form, the more branches and side branches it will have. Therefore, the lower the temperature, the less detailed the structure.

The third growth behavior of snowflakes is sharpening. Sharpening pushes the crystal growth to thin, flat plates or thin hollow columns. The growth of a faceted surface depends on the width of the facet. When the crystal's terrace is approximately less than 100 molecules wide, it is easier for molecules to attach to the top of the terrace. Per Snow Crystals, "when a corner grows, it produces narrow faceted terraces. A narrow terrace grows faster than a wide terrace, and the growth then adds more terraces that are even narrower than before" (Snow Crystals).

Artificial Formation of snowflakes

Artificial formation of snowflakes is becoming popular to create snowflakes for photographs. A scientist named Kenneth Libbrecht was inspired to begin artificially creating snowflakes after a trip to his hometown in North Dakota. Libbrecht said, "I realized that a lot about snowflakes is just not very well understood, and that ice is a pretty inexpensive material to work with". The formation of a snowflake is a very complex process. Libbrecht had trouble isolating one single flake. It was easy to create frost which is a collection of ice crystals, but isolating them took him a while. His snowflakes are created in a cold chamber in his lab, and take about 45 minutes in total. He begins with a piece of glass and places many microscopic ice crystals onto it. He puts the glass under a microscope and blows slightly warmer, humid air onto the glass. The water vapor freezes to the crystal forming a snowflake, like the process which is done in a cloud (Stromberg). Branching is what gives the snowflake the base for its symmetric design.

After years of trial and error to create an artificial snowflake, Libbrecht discovered a way to create what he calls “designer snowflakes”. After experimentation, he has figured out what conditions create each type of snowflake, so now he can design his own snowflakes. Libbrecht took his wealth of information and created his own book. He decided that the photos taken by Bentley in the 1930’s were obsolete, so decide to begin photographing his own. He has created his own specialized equipment to take the photos, and uses colored lights to make the features of the crystals more prominent (Stromberg). Many people believe that snow crystals are white, however they are clear. Snowflakes are only white when there are many reflecting off each other. The colored lights make the clear crystal easy to view. Libbrecht’s images are still widely viewed today.

Structure

Snowflakes have a fractal structure because of the way they are formed. Snowflakes are patterned because of the internal order of the snow crystal’s water molecules. These water molecules arrange themselves in predetermined spots to form a six-sided crystal. Since the crystal is surrounded on all six sides by the same conditions, the crystal remains mainly symmetric. The intricate shape of each of the six arms depends entirely on the atmospheric conditions. A crystal could begin to form on way, but even the slightest change in conditions will change the structure. Since all 6 sides experience the same change, it remains symmetric

(NOAA). There are 10 different types of snowflake shapes. The two most commonly thought of shapes are plates and stellar crystals. Other shapes include columns, needles, spatial dendrites, capped columns, irregular particles, graupel (soft hail), Ice pellets, and hail (Conners). A snowflake's structure will always be a six-sided figure, but the detailing will change based on different factors.

A snowflakes' pattern changes based on the conditions it is exposed to. The most intricate snowflakes are formed when there is moisture in the air. Snowflakes formed in less humid conditions are typically the simpler shapes. The temperature is the factor that decides which shape the flake will be. According to Conners, "Snowflakes formed in temperatures below – 22 degrees Celsius (- 7.6 degrees Fahrenheit) consist primarily of simple crystal plates and columns whereas snowflakes with extensive branching patterns are formed in warmer temperatures" (Conners). Based on the information about the different types of snowflakes, people generally think of the snowflakes formed in warmer and humid conditions to be the most beautiful.

Snowflakes have approximate symmetry, meaning that they are almost symmetric. Since each of the six arms grows independently, there is no way that they could all grow exactly the same. Each side of the snowflake is exposed to slightly different environmental conditions. While these differences are small, they can still make the shape slightly different. The snowflake is constantly turning and falling giving each arm a different flight path. Usually the asymmetries aren't apparent unless looking for them. Six-fold symmetry is seen because of the arrangement of the water molecules. The crystal structure of a snowflake is three dimensional. Only stellar plates are thin and flat. All other snowflake shapes are three dimensional. When snow crystals begin growing, they start as basic hexagonal prisms, and from there they are further developed (Snow Crystals).

Why are no two the same?

While it is technically possible for two snowflakes to be the same, it is extremely unlikely. They all have the same hexagonal shape; however, their details will almost always vary. These variations are produced by the specific conditions the snowflake goes through in the air (Griffin). Since no two snowflakes will have the exact same combination of temperature, humidity, time of day, or exact locations, no two will look the same (King). The beginnings of snowflakes have very little variation. If these fell to the ground, all snowflakes would look about the same. As the crystal grows, more water vapor attaches to the crystals, and the rough edges become a branch. Each branch can have multiple sub branches, making endless shape possibilities. A typical snowflake has about a quintillion molecules (Palmer). Because of the number of molecules in each snowflake, it is unlikely that any two snowflakes would be the same.

Leaves

Size & Shape Variation

The sizes of leaves can vary for many different reasons. The first reason being plant species and the location of the plant. The climate is a major factor in leaf size to ensure regulation of temperature. The larger the leaf, the more light it can absorb. In hot climates, leaves tend to be smaller, to ensure that the plant doesn't overheat. Leaves will grow larger and angle towards the sun in colder climates. Leaves high in the tree canopy receive more light, therefore can be smaller. Leaves lower in the tree canopy must be larger to absorb more light. A single tree can have many different sized leaves based on the location of the branches and surrounding environmental conditions. Each plant can produce different sized leaves based on the season.

The leaf shape can change as well. Leaf shape is also widely determined by the climate. Leaves that are thin and broad provides the maximum amount of surface area on the leaf for cold, moist environments. Leaves that have well defined lobes are stronger and more resilient against wind damage. It is not uncommon for a tree to have leaves with lobes on the outside of the canopy, but leaves without lobes nestled inside the canopy. For example, a small oval leaf makes it easy for wind to carry away heat and water vapor (Graham). The leaves on trees aren't always symmetric because the elements that each area faces can be different. Each leaf is generally bilaterally symmetric, but the whole plant or tree is not.

Symmetry & Arrangement

Leaves are not truly symmetric. Leaves always appear as Fibonacci numbers. This is important because it ensures that no leaf will cast a shadow on another. Fibonacci number of leaves gives all leaves an equal amount of sunlight and air. Since leaves do not overlap each other, each leaf can catch the same amount of water, which flows down through the body and reaches the roots. Each plant has a specific ratio for leaf arrangement, ensuring that all leaves are given the elements necessary for their survival (Graham). The leaf divergence ratio is common among similar plant species, and can determine how many leaves a plant will have.

Leaves have some elements of bilateral symmetry, but they show symmetry in their leaf arrangement.

Leaves have some aspects of symmetry. Leaves contain bilateral symmetry. bilateral symmetry occurs when two planes are the same. Leaves are the same when folded in half, giving them bilateral symmetry. Leaves also have dorsiventral symmetry; Which is when only the left and right are the same, and the front is different than the back. Dorsiventral symmetry is found in most leaves because of their unique vein patterns visible on the front and back. Occasionally dorsiventral symmetry can change based on mutations in the genetic code of the leaf or from evolution of the shape. Leaves do not typically have rotational symmetry, however, they do contain bilateral symmetry in their shape as well as dorsiventral symmetry in their vein structure.

Animal preference

It has been discovered that animals prefer to eat leaves that are symmetric. A study was done on giraffes and other vegetarian animals at a zoo. The study showed that the leaves eaten last, were the asymmetric ones. After a feeding, researchers counted the symmetric and asymmetric leaves left on the tree. 9 out of every 10 times, the giraffe chose to eat a symmetric leaf found on the tree. According to the study, 90 percent of the symmetric leaves were gone after the feeding. The majority of leaves that were left on the tree were asymmetric, showing that animals generally prefer to eat symmetric leaves (Smith). This study helped to show that animals have an innate preference for symmetric leaves.

Flowers

Size, Shape, and Color

The size of a flower typically depends on a couple of factors, including genetics and location. According to a study by Frey and Bukoski, “The degree of floral rotational asymmetry was strongly associated with decreased flower size and decreased flower size and decreased pollen production” (Frey and Bukoski). According to the study, flowers that are asymmetric tend to be smaller and produce less pollen than the flowers which are symmetric. It is believed that there is a correlation between the flower appearance and the amount of pollen. According to the study on pollination, symmetric flowers tend to produce more pollen (Frey and Bukoski). It is likely a case of evolution that changes the size and shape. Since smaller, symmetric flowers tend to be preferred by pollinators, the flower has likely evolved to accommodate this. If asymmetric flowers tend to have less pollen, the flower could evolve to become more extravagant. This is likely to attract pollinators to the flower.

Petal shape and color depends on the plant’s DNA. The genetic code embedded within a plant’s cells generally determine the color and shape. DNA provides the organelles with the information they need to create a certain color and size flower. Often times, this DNA is changed, either accidentally or purposefully. DNA can be changed either accidentally from a mutation during reproduction or during cross breeding. This mutation can be so small that it is unnoticeable, or can be as large as changing the color of an entire flower. Cross breeding occurs when two different plants (or different plant colors) breed accidentally. This can cause a change in color. DNA can be changed purposefully in two different ways. The most common way is by artificial pollination. Humans will often purposefully pollenate two different flowers to get the look they desire. It is also possible for Humans to artificially change the genetic code using microbiology. A flower can change color or size based on a mutation, causing asymmetry of flowers within the same species. The petals on a flower are generally symmetric, either rotationally or bilaterally.

Symmetry & Arrangement

Flowers are generally symmetric. Angiosperms are flowers that are constructed of organs and petals. Flowers generally have either radial or bilateral symmetry. Flowers that have radial symmetry are called actinomorphic flowers. These flowers can be divided equally on more than one plane. Radial symmetry is seen when all a flower's petals are identical in size and shape. Flowers that have bilateral symmetry are called zygomorphic flowers. These flowers can be divided equally in only one plane and are symmetric bilaterally. Zygomorphic flowers tend to have a more complex structure, often containing more visible organs. Zygomorphic flowers usually tend to attract more pollinators because of their appearance. (Frey and Bukoski).

Bee preference

Pollenating animals generally prefer to pollenate plants with symmetric flowers and symmetric leaves. According to a research study done by Frey and Bukoski, "Insect visitors preferentially visited smaller, symmetric flowers over larger, severely asymmetric model flowers" (Frey and Bukoski). The study deducts that this preference wasn't solely on the look of symmetry found in these flowers. Since rotational asymmetry was strongly associated with decreased flower size and pollen production, this was likely the culprit for the data findings. Bees innately would be more likely to visit the symmetric flowers that contained more pollen. These flowers likely contained more pollen because they were symmetric, which would explain the data. The authors do mention a possible connection between an innate preference of symmetry commonly found among animals (Frey and Bukoski). Bees tend to prefer visiting and pollenating symmetric flowers over asymmetric flowers.

Conclusion

Symmetry is naturally occurring in nature. It can be found in most aspects, it's most notable being Snowflakes, Leaves, and Flowers. Snowflakes display six-fold rotational symmetry. Snow crystals are formed in such a way that they always have 6 arms, displaying symmetric patterns on each. Each snowflake is different, which means that there is no symmetry found among snowflakes in general. Symmetry can be found in leaves. Leaves display approximate bilateral symmetry, meaning they are generally symmetric when folded in half. Leaves show symmetry in their arrangement, as they are arranged in a Fibonacci sequence. Leaves on the same plant are often different sizes and shapes because of the environmental conditions each endures. Leaves are not always the same size on either side of the plant or tree. Branches and leaves grow depending on their environment, causing asymmetries of the entire plant. Flowers display many traits of symmetry. All flowers either have bilateral or rotational symmetry. Bilateral symmetry is typically found in larger, more intricate flowers. These flowers often contain less pollen than their rotationally symmetric cousins. Rotational symmetry is most often found in smaller flowers. Nature finds a way of integrating symmetry into its’ various elements.

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